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ELECTRONS FROM MOLECULAR HYDROGEN IN HI REGIONS

by

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ABSTRACT

We show that the principal source of electrons in H I regions is the photoionization of vibrationally excited molecular hydrogen by starlight near 1000Å.

We now wish to use this vibrational energy to reduce the energy threshold for ionization and thereby couple the starlight on the long wavelength side of the Lyman limit into the gas.

For each vibrational level v" ≥ 5 there will be a photoionization cross-section, σ, and an effective bandwidth, $\Delta\lambda$, for the photons that can produce photoionization. The rate of production of electrons by this process is

$$\sum_{v''\geq 5} F \left\langle \sigma \Delta\lambda \right\rangle_{v''} n(H_2, v'' \geq 5) \tag{1}$$

where F is the flux of photons $cm^{-2}s^{-1}Å^{-1}$ in the relevant wavelength range.

Let us consider a cloud of molecular hydrogen near a hot star. The stellar radiation destroys the H_2 by the process we have discussed earlier (Stecher and Williams 1967). The number of electrons produced by photoionization of H_2 is the rate (1) times an appropriate time. In this case, the appropriate time is the lifetime of H_2 against photodestruction by absorption in the Lyman bands, and this is a time shorter than electron recombination. Hence we obtain:

$$n(e) = \frac{1}{\beta_{1,d}} \sum_{v''\geq 5} F \left\langle \sigma \Delta\lambda \right\rangle \alpha_{v''} n(H_2) \tag{2}$$

where $\beta_{1,d}$ is the photodestruction rate and the subscript 1, d, denotes that the destruction is performed by absorption of line radiation. The term $\alpha_{v''}$ (Stecher and Williams 1972c) is the equilibrium fraction of H_2 in each excited vibrational level and it depends linearly on the rate of excitation in the Lyman and Werner bands, $\beta_{1,e}$, thus

We have shown (Stecher and Williams 1967) that the radiation field present in H I regions can photoionize molecular hydrogen by means of a two step process. This two step process is not the dominant destruction process for molecular hydrogen under ordinary conditions but does provide a source of electrons in mostly neutral interstellar clouds. Large column densities of molecular hydrogen have been observed by means of rocket instrumentation (Carruthers 1970, Smith 1972). On the order of half of the total hydrogen in interstellar clouds is predicted by Hollenbach, Werner and Salpeter (1971) to be in molecular form. Assuming that this is the case, we shall now show that the principal source of electrons in H I regions is the photoionization of vibrationally excited molecular hydrogen by starlight near 1000Å.

The absorption of a photon in the Lyman or Werner bands of H_2 is immediately followed by emission to the ground state. Using the f-values of Allison and Dalgarno (1969), Cartwright and Drapatz (1970), one may show that eightly-five percent of the absorptions in the Lyman and Werner bands and the subsequent emissions leave the molecule in a vibrationally excited state. Molecular hydrogen is homonuclear and has no dipole moment. The lifetime against radiative decay is, therefore, long, i.e. ~ 10^6s (Dalgarno 1972). We have recently discussed the interstellar abundance of vibrationally excited H_2 (Stecher and Williams 1972a, b, c) in connection with the formation of diatomic molecules. The vibrational energy can overcome the endothermicity of some relevant reactions.

$$\alpha_{v''} = K_{v''} \beta_{1,e} \quad (3)$$

where $K_{v''}$ is on the order of 5×10^4.

Now $\beta_{1,e}$ and $\beta_{1,d}$ are very simply related. It has been shown by Dalgarno and Stephens (1970) that for a radiation field which is constant with wavelength that 23 percent of the Lyman band and none of the Werner band absorptions lead to dissociation into the vibrational continuum. Thus, all the Werner band absorption for $\lambda > 912$Å contribute to $\beta_{1,e}$, but only 77% of the Lyman absorptions contribute to $\beta_{1,e}$. (See also Allison and Dalgarno 1969, Cartwright and Drapatz 1970). Thus $\beta_{1,e}/\beta_{1,d} = 12.5$ and we have the interesting result that the electron density produced by the mechanism we are describing depends only on the continuum flux of radiation which causes the ionization and the H_2 density but is independent of the radiation giving rise to vibrational excitation and to photo-destruction. Taking the average cross-section, σ, to be 10^{-17} cm^2 and assuming that the average $\Delta\lambda$ = 100Å we get $\langle\sigma\Delta\lambda\rangle = 10^{-15}$ cm^{2}Å and obtain

$$n(e) \simeq 6 \times 10^{-9} F\, n(H_2) \quad (4)$$

where allowance has been made for all suitable v" levels and F is the flux around 1000A in photons cm^{-2}s^{-1}Å^{-1}.
If we take the initial density $n(H_2)$ of the cloud to be 10^2 cm^{-3} and let F be 10^6 photons cm^{-2}s^{-1}Å^{-1}, (equivalent to 30,000°K black body diluted by a factor of 10^{-14}) we obtain $n(e) = 0.6$ cm^{-3} or $n(e)/n(H) = 3 \times 10^{-3}$ which is a factor of 10 greater than that produced by the photoionization of carbon and for a given flux depends linearly on the H_2 density.

The interpretation of pulsar data (Hjellming, Gordon and

Gordon 1969) requires an ionization rate $\zeta \sim 3 \times 10^{-15} s^{-1}$. A similar value is found by Reynolds, Roesler and Scherb (1972) from Fabry-Perot measurements of the diffuse Hα and Hβ night sky emissions. Spitzer and Tomasko (1968) find that a ζ of $6.8 \times 10^{-18} s^{-1}$ is the minimum value consistent with the cosmic ray radiation observed at the earth. They find a value of $10^{-15} s^{-1}$ is possible for certain supernova models. Silk and Werner (1969) find $\zeta = 4 \times 10^{-17} s^{-1}$ from observed x-rays and somewhat higher values for an extrapolated x-ray spectrum. Neither easily explain the observed ionization.

However, a cloud of H_2 near a hot star receiving 10^6 photons $cm^{-2} A^{-1} s^{-1}$ has an ionization rate of $\sim 6 \times 10^{-11} s^{-1}$. Thus if this situation occurs for 10^{-4} of the interstellar hydrogen in the galaxy the observed ionization rate can be accounted for. Since one percent of the gas is ionized by starlight (Allen 1963) it would be reasonable to suppose that the case we envision here will be met. Detailed models can be calculated but are beyond the scope of this letter.

Hollenbach, Werner and Salpeter (1971) give a formation rate for molecular hydrogen of $10^{-17} n n_H \; cm^{-3} s^{-1}$. It is interesting to note that if all the hydrogen is in clouds with densities of a few hundred the formation rate is sufficient to balance the destruction rate and still produce the ionization rate of our simple model which is around one percent of the destruction rate.

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